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ABSTRACT

This paper discusses computer simulation as a tool for teaching about phenomena characterized by a problem to be solved, a task or goal to be reached, a procedure to be learned, or an environment to be understood. Simulation is defined and characterized by an examination of both the attributes that are common to simulations, and a taxonomy (classification) of simulations based upon attributes not common to all instances of simulation. The many aspects of using simulations in the classroom are also discussed. This document was prepared as resource for the preservice and inservice training of teachers, and it points out that although simulations can be a valuable teaching tool, in order to use them effectively teachers need to be aware of their nature, what they can potentially provide in the way of learning experiences, and the provisions that must be made to optimize their use. A list of sources of existing simulations and a 27-item bibliography are attached. (Author/CMV)

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Number 8e

The Illinois Series on Educational Application of Computers

ED183188

COMPUTER SIMULATION

AND

ITS INSTRUCTIONAL USES

J.Richard Dennis

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To the reader,

This is one of a series of documents prepared as resources for the preservice and inservice training of teachers. The general theme of all items in this series is "teaching with or about computers". The booklets are the collective work of a variety of staff and students (both present and former) of the College of Education, University of Illinois at Urbana-Champaign. The project generously was supported between 1977 and 1979 by a grant from the EXXON Education Foundation. All responsibility for the content of these documents rests with the authors and does not reflect necessarily the views of the EXXON Foundation. It was my extreme pleasure to direct this effort throughout.

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INTRODUCTION

Among the early applications of computers, one can find frequent mention of attempts to replicate the behavior or function of a wide variety of physical or social phenomenon. Such replications are referred to variously as simulations or as simulation games. This type of computing activity has accelerated rapidly as the size and speed of computing devices has increased. But also, simulation activities are pursued to increase one's understanding of certain formerly remote or inaccessible phenomena. It is this characteristic of computer simulations that has lead to their use as direct instructional devices in schooling settings.

Several areas of instruction or training have come under increasing influence of simulation as a means of facilitating achievement of learning objectives. Medical schools have used simulations for instruction in disease diagnosis and in drug prescription. Such activities have been reported as helpful during initial instruction, during individual student practice and study, and during the evaluation of student performance. Business schools increasingly have reported simulation activities in business problem-solving training and in other management activities. Both the civilian and military aircraft industries have become noted for extensive application of simulations in the training of flight personnel. Several authors, including Maidment and Bronstein (1973), have reported on uses of simulations in teaching of the structure and functioning of various social systems.

From the perspective of the potential or practicing teacher, there are several important issues to be addressed in a study of simulations for instruction:

1. What is a simulation?
2. In what type of instructional situations are simulations effectively applied?
3. How are simulations used in a classroom?
4. How is a simulation constructed?

The following sections are designed to assist your formulation of answers to such questions.

WHAT IS A SIMULATION?

There are several common methods used to assist in learning the meaning of a noun like 'simulation'. One of these methods is to state a definition of the word in terms of other (hopefully) more meaningful expressions. In some older dictionaries, 'simulation' was defined as synonymous with counterfeiting, the act of pretending that which is not true. The idea of a counterfeit, although applicable to the simulation setting, carries with it a negative connotation we wish to avoid. Instead we propose the following general definition:

DEFINITION

A simulation is a replication of the behavior of a phenomenon of one's universe designed to substitute for the phenomenon.

Of course, for the teacher trying to understand what simulations are, such a definition may be less than useful. This is particularly the case for the reader who has experienced no simulations first hand. If this is the case, it is recommended that you carefully examine one or more simulations. It is not necessary for our purposes here that these simulations be computerized, or that they be about phenomena in your field of expertise (a list of sample simulations is at the end of this paper). For this author, the starting points in coming to understand the general concept of simulation were a wide array of instances including airplane flight simulators, replications of stock company transactions, replications of a variety of science laboratory procedures (called simulated laboratories), replications of various business competition environments, of several machine operation or maintenance diagnosis settings, of medical diagnosis or prescription activities, and replications of population growth, ecological systems, and economic systems to mention but a few.

For our purposes here, we have confined our attention to instances of simulation in which the purpose of the replication has been an educative one. Whether there are simulations not having an educative purpose is debatable. At the very least, simulations are built to confirm one's understanding of the operation of a phenomenon, an activity itself having an educative outcome.

A TAXONOMY OF SIMULATIONS

Another method of building understanding of a noun is to identify all those attributes not common to instances of the noun, to describe or name each such attribute and thus to formulate a taxonomy for the instances of that noun. For our purposes here, namely using simulations in instructional processes, we shall catagorize simulations in terms of the learning goals or objectives which each seems to possess. From this point of view, there are three types of simulations:

1) Replicable Performance Simulations:

The learning outcome is an expected replication of a specifiable performance.

2) Information Retrieval Simulations:

The learning outcome is information in the form of facts, priciples, or understandings, all of which are specifiable and/or quantifiable.

3) Encounter Simulations:

The learning outcome is the "experiencing" of a situation. One is expected to become aware of (perhaps) vaguely defined possibilities or probabilities of the situation. The learning goal is awareness of variability among the consequenses, and procedures for assessing the magnitude of this variability.

In the following discussion we present in more detail, the characteristics of these three types of simulation.

Replicable Performance Simulations

All simulations of the Replicable Performance variety have as their goal an expected repetition of a series of behaviors in an optimal sequence. The associated real performance is task oriented, the task is definable, and optimal task achievement sequences also are definable. Examples from this category are diagnostic simulations for various fields, procedure simulations from the trades or from laboratory settings, flight simulations, etc.

The phenomenon associated with each member of this class has in it a goal to reach, but reaching that goal may or may not involve problem solving. Each such phenomenon has two components, a procedural logic, and a procedural execution. The role of this simulation is to gain proficiency to some degree with the procedural logic. In doing so, however, opportunities are presented in the simulation that are not present in reality. These are opportunities deliberately to explore or to have surrogate experiences with the consequences of other than optimal actions and decisions. Learnings of the procedural execution may be present to a widely varying degree, with some instances including no surrogate of physical performance, while other instances incorporate physical performance with the logic simulation to a high degree of fidelity.

An important characterizing feature of this category is the relationship between the learnings of the simulation and optimal performance in the real setting. Behaviors or knowledge mastered during the simulation have associated with them a guaranteed applicablity in the real setting. This is not to say that transfer of the learning is guaranteed but, rather, that when transfer does occur, the effectiveness of the application is guaranteed. This applicability is assured because the procedures are definable, consequences of actions or decisions are definable, and there is a certainty or known expectation between each action or decision and its consequences.

Information Retrieval Simulations

An Information Retrieval Simulation is one whose goal is the securing of information. No clear task or performance goal is obvious in the setting. The associated phenomenon is a process or system which operates under a set of principles or laws. In the absence of clear tasks or goals, there are no optimal solutions or strategies involved. Examples of this style simulation are those that replicate for experimentation a variety of physical or social processes such as genetic reproduction, economic systems, ecological systems, or other scientifically based phenomena.

The phenomenon underlying this type of simulation is well understood and the interactions of its components or variables also are defined and understood. The role of the simulation in such a situation is that of transmitting information in several forms. In the simplest form, the information is comprised of facts about states of the phenomenon. At more sophisticated levels, the information is in the form of principles of cause and effect in the phenomenon or of principles for achievement of steady states.

In information retrieval simulation, the participant may have very vague goals or may be pursuing the effects of definitely specified experiments on the surrogate environment. To do so, the participant makes changes in variables of the phenomenon and then seeks data on the state changes accruing from such actions. Skills are not an outcome of the simulation except, possibly, in the remote realm of inquiry or experimental skills. No performance directly is implied by participation in the simulation or the resulting learnings. Learning is defined by the extent to which the defining of experiments, followed by observation of consequences, can be changed into an ability to define experiments and to predict consequences prior to execution of the simulation. An intermediate stage in this learning continuum is the ability to design an experiment and to explain the results once they are observed.

Encounter Simulations

The instances of this category are concerned with phenomenon that are neither completely definable nor predictable. The purpose of the simulation is to experience achieving a goal or to function effectively in a setting in which there exists no clear optimal procedures or principles. These phenomena have loose cause and effect relationships that are, at best, probabilistic and whose behavior greatly is influenced by considerations other than scientific or logical ones. Examples from this category are simulations of business competitions, of discipline episodes in teaching, of locating missing persons in unfamiliar environments, of a teacher's first year of experience toward achieving tenure, and the wide variety of social role playing activities.

The phenomenon underlying such simulations are not well understood. The variables influencing the behavior of the phenomenon are not all identified and the interactions among known variables are influenced by sometimes unpredictable, chance events or conditions. The role of simulation in this case is to provide opportunities to gain familiarity with possibilities and with the nature of these chance influences. There are few cause and effect relationships to be discovered or understood. One hopes to derive understandings, however incomplete, of the varying relationships between precipitating events or actions and the array of likely or unlikely reactions of the environment. No direct transfer of experience is guaranteed. Neither is a general applicability of resulting learnings guaranteed.

Obviously this is the type of simulation which we know least about. It is not unlike the problem solving category found in various taxonomies of cognitive behavior. Relative to any one phenomenon selected, we generally can identify very good or very bad interactions or performances with that phenomenon. However, the principles, ingredients, and systematization of such behaviors are missing.

USING SIMULATIONS IN TEACHING

Before a teacher can make the decision to use a simulation (or other istructional materials) with students, it must be possible to answer the question:

What learnings are produced by the experience?

In the case of simulation, still other considerations must be recognized. Computer simulations are expensive to design and implement. Also, they tend to encourage multiple executions by students. From a learning point of view, this, of course, is good. School activities that precipitate extra involvement of the student are rare. However, multiple executions by each student can cause serious classroom management problems and may require some coordination with other teachers using the computer if terminals are few in number.

To date, few reports in the research literature of instructional simulation have included data on carefully measured effects or outcomes. Quite often, one sees the statement that the simulation experience produced essentially no difference over conventional methods in the learning outcomes. Such findings would not support expenditures for this style activity for very long. There are in the research literature rather consistent reports of significantly improved student attitudes when using simulations of one type or another.

The more important question to be asked of a learning setting is the following:

What <u>new</u> learnings are produced by the activity.

Some researchers have attempted to answer this question for simulations. Bewley, Holznagel and Klassen (1975) hypothesized that experiences with simulation result in a type of cognitive development. They view a simulation as a procedural symbolic system, as contrasted with conventional teaching materials composed of sentences and pictures. Extracting information from such a symbolic system would require a much different set of learning skills than are required by conventional materials. So, they argue, experiences with simulation should help to develop this new set of learning skills. An assumption in this view is that any experiences promising the development of different learning skills are good.

The question should be raised whether simulation experiences are appropriate for all students and whether certain students might benefit more from one style simulation than from another. McKenney and Keen (1974), in studies of problem solving methods

among graduate business students have identified two distinct styles of intellectual operation. Briefly, some of us have a systematic style characterized by planning and organization, while others of us have an intuitive style characterized by following hunches, lack of early commitment, and frequent redefinition of the problem. McKenney and Keen also have identified two distinct methods in which we collect information about a problem. Some are preceptive information gatherers, who appear to begin with a concept (or system) of arranging and weighing information. Such people seem to have preconceptions of the kinds of information that should be attended to or the kind that safely may be ignored. Other individuals are receptive information gatherers. They focus on detail much more than the preceptive person. They ponder facts and clues separately, with no apparent attempts to fit the pieces together into a picture. Such persons tend frequently to "suspend judgement and to avoid preconceptions".

The fact that differing information gathering and problem solving styles exist raises many important questions about the design and use of simulations by such learners. Little is known about the appropriateness of the various types of simulation for learners possessing one or another style. On the surface, one might expect the more structured, sequential nature of Replicable Performance simulations to be more compatible to a systematic problem solver. One might expect Information Retrieval simulations to be a more efficient learning method for preceptive individuals. One might further hypothesize that Encounter simulations would be more helpful learning devices for intuitive persons than for systematic ones. At this point in time, there is a significant lack of research to assist the classroom teacher in deciding such issues.

Learning from a simulation is predicated on interaction with it. A simulation does not present its information to the student. Rather it surrenders information as a consequence of student interaction. However, the simple sum of the effects of the pieces of information extracted from a simulation appears not to be equivalent to the totality of the important learning. The dynamics of the setting and the extent to which the participant can "live" these appear to be significant contributing factors to learning. Feedback on individual actions and decisions should be important in structuring one's perceptions. Even more important should be the opportunity to experience, even second hand, the highly undesirable courses of action in a simulation.

The extent to which participant identification with a simulated situation takes place is a significant issue. The argument would be that identification promotes engagement in the problem and a responsibility for actions which would be exhibited by concern over realized harm or by mild anxiety at important decision points. Kemmis (1977), reporting on evaluations of

computerized patient simulations in use at the Glasgow Clinical Decision Making Project, University Department of Medicine, Royal Infirmary, Glasgow cites data on outcomes of such activity:

> "As students work through the case, there is no doubt that they imagine themselves to be real doctors working on a real case. The plot of the drama they are acting out is built into the machine; it controls the decisions to be taken. Identification takes place not through watching a character on a stage acting out a role before them; their identification takes place through participation in the play (with the machine "reading the lines" of the other significant actor, the patient)."

The Glasgow Project has produced some evidence of attainment of these learning outcomes. Evaluation in this case took the form of having students rank order, from most to least desirable, an array of available courses of action in a situation. Similar rankings were acquired from practitioners with varying levels of "real" experience. Results showed students who experienced the patient simulations performed on the ranking test more like graduates with 1-2 years of actual experience. Apparently, the simulations did contribute to significant changes in decision making behaviors.

The Glasgow Project also reported evidence of significant incidental learnings from simulations. Specifically, because the simulations required specification of prescribed drugs and dosages at various times students gained a type of experience not found in other aspects of the Glasgow medical program except in pharmacology lectures. In the student's view, such lectures are quite remote from actual practice.

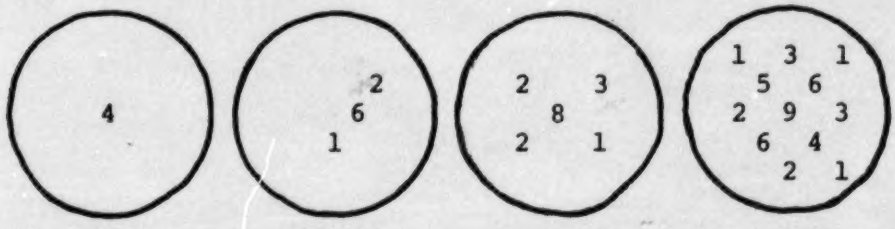
Medical diagnosis simulations have a context in which the consequences of an erroneous decision have attached to them a significant human value, that of "sacredness" of life itself. Diagnostic simulation also presumably would be effective in the training of "diagnosticians" in other realms of activity (e.g., automotive, electronic, etc.) who correctly must identify faults and institute appropriate corrective measures in systems of one type or another. The question arises as to the generality of both the fact of, and the effects of, identification with a simulation. Do electronic diagnosticians, for example, "live" a simulated electronic failure and its solution to the same degree that Glasgow Project students "live" their patient diagnosis simulation? Are the effects of this "living" comparable across simulation types and settings?

A simulation to the learner is not an entity by itself. Each learning experience is embedded in a much larger learning environment with predecessors and successors. The relationship between and among all of these elements is, at this, point in time, quite hazy. For example, imagine a science laboratory experiment for which the learning goal is a modicum of proficiency at a particular procedure. This instructional setting might include some necessary introductory literature, a teacher demonstration of the laboratory procedure, a simulation of the logic of the procedure, and a means of practicing the procedure prior to a demonstration that the objective has been met. Is there an optimal order or mix for such events? Can any of them be omitted and still maintain learning efficiency? Can extended practice with the logic simulation replace portions of the live practice on the procedure? Can the objective efficiently be met without a live demonstration and instead, have students follow the introductory literature immediately with the logic simulation?

It is suggested that much learning can be derived from the design and building of a simulation. This raises some questions and prospects for the classroom teacher inclined toward simulation. What are the relative values of executing a simulation versus building one? What are the implications (if any) of permitting one (or a few) student(s) to build a simulation for others in the class or school to experience? Dennis (1975) reports an example of simulation building by a student and the manner in which significant new learnings might be encountered in such experiences.

> "The student became interested in simulating the growth of bacteria on agar plates. A biology instructor discussed growth of the bacteria and growth rates with the student until he had what was felt to be an understanding of the process. (The student) then built a computer program modeled after his understanding of the process at the time.
>
> "When one executes (the student's) program, the computer first says that you have an agar plate and presents a choice of 5 or 6 nutrients which may be put on the plate. Having chosen, you are given a choice of several bacteria to grow in the nutrient. Having made this choice, the computer asks for a density for the bacteria (from 1 to 9 parts per unit of area in the dish). This amount of bateria is "deposited" in the center of the plate and is shown by the computer by "drawing" (using typed characters) a circle for the plate and typing the chosen number in the center. Now you are asked for the time interval T1 between

observations of the growth and the total time T2 you wish the experiment to run. (The time intervals do not actually pass, but are used in calculations of the simulation). The computer then begins the growth process simulation. For each time interval T1, the computer draws a new dish with densities of bacteria at that time recorded. after 3 or 4 intervals, your typeouts might look like this:



"At this stage of an early execution of the program, the student noticed that after a few observations, the density of bacteria in the center ceased to increase and, in fact, began to decrease. This was a surprise, an apparent difficulty in his model. In fact, his understanding of the process had been incomplete and yet his model had patterned so accurately that part of reality he understood, it also modeled the part of reality still unknown to him. A consultation with the biology instructor brought out the fact that, over time, the nutrient in an area is exhausted and the bacteria begin to die in their own waste. A check of the computer program, from the point of view of this new finding, revealed how (the student's) algorithm had correctly accounted for the phenomena without an awareness of it."

It is not uncommon for students to expand or restructure their view of a phenomenon during the act of building a simulation of it. In fact, it might be argued that the one(s) learning the most from a simulation are those who build it.

A final, but by no means last, consideration of the teacher regarding simulation relates to the batch/interactive decision in the instructional computing setting. Most commercially available simulations (e.g., the Huntington II simulations) are designed for interactive execution by the student. As mentioned earlier, this frequently puts a strain on the school's computer facilities if many students are expected to experience the simulation at one time. The teacher in such situations seriously must address the

real effects to be gained from interactive mode. In cases where interaction is not mandatory, some alternatives are available that, with a minimal effort, greatly can increase the student handling ability of a simulation. Such economy measures can make more computer activities available to a group of students or make computer activities available to a larger portion of the school.

What is being raised here is the prospect of changing the simulation so that it will operate from, say, mark-sensed card (batch) input. Usually these changes are minimal in a program and can be done by a student. Following this suggestion, a typical computer augmented class might look like this:

> As the students enter the class, a CRT terminal is attached to a large television monitor at the front of the room. The teacher opens the discussion of the day by describing a phenomenon of importance in the subject. The discussion is general, with some mention of principles or properties governing the phenomenon. After a few minutes, the teacher turns to the CRT and calls up an interactive version of a simulation of the phenomenon. The next several minutes are spent demonstrating and experiencing (as a group) the workings of the phenomenon with the aid of this simulation. Soon, however, the students begin raising questions like "What would happen if (a certain) change were made in the conditions of the setting?" A couple such changes might be tried interactively to examine their results. By now nearly every student in the class will have a change they would like to make to see what happens.
>
> At this point the teacher passes out some mark-sensed cards and a one-page description of what columns on the card to use to record particular pieces of information, what symbols to use to separate data, how to record one's name, etc. The teacher (perhaps using an overhead projector) walks the class through the recording of a sample experiment with the simulation. The class is then set (either individually or in small groups) to designing and recording one or two experiments it wishes to conduct. While students are doing this, the teacher calls up a batch version of the simulation and prepares a card reader and printer for operation. The student experiment cards are collected, put into the reader, the batch program is run, and results begin coming out on the printer. Each student's results occupy a separate page so that they quickly may be

separated and distributed to the class. After these result are compared or discussed, new hypotheses emerge. The process is repeated (time willing) or the students are given a computer assignment for the next day.

This example is appropriate for many instances of Information Retrieval or Encounter type simulations and illustrates the flexiblity that can be gained by mixing batch and interactive operation of a computer system. The example also implies some very important study or experimenting behaviors that students need to know.

There are two important strategies for systematically investigating the behavior of an environment with the aid of a simulation. The first of these we shall call the "terrain mapping" strategy. The name suggests the purpose of the strategy, it is intended to help the student form a gross picture of the environment, looking for data regions that produce relatively "flat terrain", for data regions with varying "mountain terrain", and for data regions that may contain severe "cliffs or caverns". The analogy is a good one. What one seeks during such explorations is data combinations that result in stable states of the environment, that result in uniform increases or decreases in the environment, or that result in discontinuities in the environment. This type of searching and exploration must be done systematically with some planned scheme of uniform step changes (e.g., holding all but one variable constant as its values are increased by multiples of some increment).

This "terrain mapping" strategy frequently serves to suggest data regions warranting more detailed investigation. Among these are regions in which changes from increasing to decreasing behavior are encountered (or vise versa), regions where discontinuities may occur, or regions where particular stable states are achieved. This is where the second investigation strategy comes into play--one we shall refer to as the "neighborhood" strategy. This strategy is used to get a very focused, magnified view of a "small" data region or neighborhood. One defines the data boundaries of an interesting neighborhood and systematically "walks around" that neighborhood in uniform, very small steps.

These strategies are ones that are almost impossible to include in conventional teaching environments because of the complex data manipulation and calculation usually required. Here again is the suggestion of a type of "new" learning that can be facilitated by inclusion of simulation experiences in the teaching plan.

Study Activites

1. Carefully examine (if possible execute) 2 or 3 simulations from your teaching field (or a related field). Determine which category of the simulation taxonomy (Replicable Performance, Information Retrieval, or Encounter) best fits each of the instances you choose.

2. Using the same simulations you selected from exercise 1, list what you believe to be the learning outcomes deriving from use of each. Wherever possible, relate the learning outcomes to the objectives of school subjects and topics. Also, note any instances of learning outcomes that are incidental to school subjects or topics.

3. Develop a detailed lesson plan built around a simulation experience with a phenomenon in your field. Be sure to include details of your introduction/presentation of the simulation of the model and its priciples, as well as details of activities with the simulation the student will do.

**

The following section should be considered as optional or additional reading for the classroom teacher. Various techniques and strategies for evaluating and constructing simulations are discussed. These topics are oriented toward program design and are not necessary for a general understanding of simulations. This material is important for those teachers who attempt to construct simulations for classroom use or who encourage their students to engage in simulation building. It also is important for those charged with evaluating commercially available simulations for classroom adoption.

ATTRIBUTES OR PROPERTIES OF A SIMULATION

As a recreation of an aspect or phenomenon of one's universe, a simulation attempts to make substitutes or surrogates for experiences and interactions with the phenomenon. In so doing, these surrogate experiences may be convenient, more safe, more manipulatable, or more inexpensive than would be the experiences with the phenomenon itself.

A simulation can exist for any phenomenon characterized by either a problem to be solved, a goal to be reached, or an environment to be understood. Generally, a simulation presents as realistic a replication as possible, but this characteristic of realism usually is a constrained one. The environment deliberately is restricted to ignore selected aspects or details and one's attention is focused on a central "field" almost in the way a television camera focuses one's vision on a central subject matter of a visual field by eliminating surrounding details and complications. Some of the more pertinent complications may be included to gain perspective or realism (in the simulation realm this is referred to as "fidelity"). The phenomenon of the simulation (the subject of replication) usually is quite complex and will possess a multitude of determining variables and interactions among them. Many methods may lead to the solution of the problem, the attainment of the goal, or the achievement of the understanding. Among these numerous methods, however, some may be designated as more preferred (or "better") than the others.

One of the important attributes of a simulation is the opening scene (or scenario). It is in this part of the simulation that the setting is described, as are all those aspects of the phenomenon that readily are available or accessable in reality. Some selected irrelevancies will be included to achieve realism or to motivate or interest the participant. In the opening scene, the participant's role in the simulation is detailed, a task or goal is stated, and any limitations in time, assistance, or related resources are revealed.

Following is the opening scene from an interactive simulation of the first year of teaching called "TENURE" found on the PLATO computer system at the University of Illinois:

WELCOME TO MIDDLETOWN HIGH

"This is a simulation of the first year of teaching. During this simulation, you will be called upon to make decisions similar to those made by a first year teacher. Your goal is to obtain tenure or better.

To a great extent the principal's satisfaction with your work determines whether you get tenure or not. However, there are other factors involved as well. Certainly the performance of your students is considered as well as your reputation with pupils, faculty, and parents.

"Often there is not a 'correct' decision, only a 'best' one. Of course, what the best decision is depends upon the philosophies of your principal. There are four different principals available in this simulation, assigned at random. You will get clues from time to time about his philosophy."

FIGURE 1
Lesson TENURE on the PLATO Computer system
University of Illinois
Dr Owen Gaedes, author

The heart of a simulation is composed of a set of ordered pairs whose first components are options (choices) relative to the setting and whose second components are the responses (consequences) of instituting that option. McGuire, et al (1977) have presented four classes of option pairs usually present in situations being simulated. Their work was presented in the context of creating pencil and paper simulations (called written simulations) but applies equally well to computerized simulations.

1. Data Gathering options--methods of access to accumulated information some of which is needed to complete the task.

2. Management options--deliberate decisions or actions that can be executed in the environment. Each of these has the potential of altering the environment.

3. Consultation options--seeking authoritative help on data collection and interpretation, on making management decisions, etc.

4. Valuing options--expressions of personal attitude or feeling about the problem or setting. These are derived from an assessment of the possible value positions in the situation.

Each option pair in a simulation is of one of five types or qualities relative to the progress toward completing the task that the option achieves:

1. Necessary option--required for successful completion of the task.

2. Expediting option--not necessary to task completion but will facilitate completion.

3. Neutral option--not contributing to task completion. The participant neither is helped nor hindered in achieving the task.

4. Delaying option--impedes progress toward completion of the task but does not prevent completion.

5. Aborting option--precipitates failure to complete the task.

These qualities of the option pairs represent, in a sense, a continuum of choices that the participant can make ranging from very good choices (necessary) to very bad ones (aborting). Between these extremes, the expediting choices do so by revealing or suggesting other related necessary choices. They provide clues to necessary action. In the same manner, delaying choices may reveal or imply aborting choices. Among the expediting and necessary choices are contained all those elements which represent good choices. Similarly, the delaying and aborting choices contain all those elements which represent poor decisions by the participant or decisions based upon misconceptions.

The response part of each option pair informs the participant of the effects or changes in the state of the simulated environment which results from that choice. These changes in state may be of two types: immediate or delayed. To complicate matters further, the sequencing of the various options into a possible task completion can change their relative value on the necessary-aborting continuum. For example, in a simulation of a welding procedure, one naturally would expect the management choice of "turning on the welder" to be a necessary option. However, if this choice has not been preceded by the proper equipment and environment preparations, such action could result in mild to very serious damage to the welding machine or to the person operating it. Thus, "turning on the welder" becomes an aborting or delaying option in certain circumstances.

This suggests, of course, that among the option pairs there is a multitude of arrangement sequences or combinations of various subsets. These sequences are called Paths through the option pairs. Some of these subsets are very important for they represent sequences of actions and decisions that result in achieving the task of the simulation. These sets are called Solution Paths for the simulation. A solution path can be any sequence of option pairs of the necessary, expediting, neutral, or delaying types. Clearly a solution path cannot contain choices of the aborting kind. Among all of the solution paths, there is a small subset of such paths that represent "better" behavior by the participant than the other solution paths. For one thing, these better solution paths never contain neutral or delaying options. For another, the "better paths" represent a minimum of activity or a more efficient achievement of the task. These solution paths are called Optimal Solution Paths. Of course, there must exist at least one optimal solution path to a simulation. When the set of solution paths contains only one selection, then that one, by definition, is the optimal solution path. The optimal solution paths represent prescriptions for correct action in the context.

Each simulation has one (or more) strategy initiation sections. A strategy initiation section is a major decision point in the simulation, a point at which solution strategies are formulated. At such times, the decision among the options of data gathering, managing action, consultation, and valuing is made. The participant returns to a strategy initiation section each time all the consequences of the previous strategy decision have been realized.

There are two basic styles of strategy initiation sections common in instructional simulations, the multiple choice type and the constructed type. Following is an example of the combined opening scene and constructed type strategy initiation section of a simulation of an acid-base titration laboratory procedure:

(FRAME 1)

In this experiment you will determine the concentration of a solution of NaOH by measuring the volume of a base required to neutralize a weighed sample of Potassium Acid Phthalate.

The steps involved in the standardization are:

1) Fill the buret with base.

2) Weigh a sample of PAP and dissolve it in water.

3) Add a few drops of indicator.

4) Add base from the buret until the indicator changes color.

(FRAME 2)

In this experiment you are to determine the concentration of a NaOH solution by titration of Potassium Acid Phthalate (MW=204). The base is about 0.1 M.

What do you want to do?

>(input data here)

FIGURE 2
Lesson TITRATE on the PLATO computer system
University of Illinois
Dr Stan Smith, author

Notice that following the opening scene, the participant is presented the question "What do you want to do?". At this point, the participant may request a variety of information, may initiate one of several steps in the laboratory procedure, etc. However, the participant has the responsibility both of knowing what some of the available choices are and of knowing or determining an appropriate order in which to make the choices.

For contrast, here is an example of a multiple choice style strategy initiation section taken from a simulation of an arc welding procedure:

Your assignment is to draw a bead using the stick-arc welding equipment.

What would you like to do?

Enter the number of your choice:

1)Inspect the materials.

2)Initiate the arc.

3)Inspect the work area.

4)Inspect the equipment.

5)Shut down and clean up.

6)Exit this program.

FIGURE 3
SIMU1 Stick Arc Welding Simulation
Institute of Aviation, University of Illinois
Dr J Richard Dennis and James T Stewart, authors

In this example, the choices are cearly spelled out to the participant. The participant has only to know, or to determine, a proper order in which to make the choices.

The last important component of a simulation has essentially nothing to do with the content or logic of the replication but, rather, is important for optimizing the operation of the simulation and for facilitating the participant in completing the task. These are a collection of transition messages which inform the participant of mechanical features such as what to do to keep the simulation mechanically progressing from page to page, when and what type of help or other assistance is available, etc. In computerized simulations, these are the messages telling the student what to do on the keyboard or other input device to initiate the various choices being made.

In summary then, the important components of any simulation are the following:

1)The phenomenon to be simulated.

2)The opening scene presented.

3)The collection of option pairs.

4)Solution paths.

5)Optimal solution paths.

6)Strategy initiation section.

7)Transition messages.

As we shall see, each of these components must seriously be considered both when building a simulation for possible classroom use and when evaluating an existing simulation.

Basic Simulation Structure

The previous section has described the necessary ingredients of a simulation intended to be used in instruction. What emerges from this discussion is a strategy for fitting these components together into an operational whole. The flowchart in figure 4 presents this structure.

The algorithm illustrates an important feature of simulations designed for instruction. This is the disposition of the consequences of various option selections. There are two types of consequences involved in the setting under consideration here. Consequences, in reality, either may be immediate or delayed in time. From a fidelity point of view, a simulation accurately should reflect these designations. However, some consequences are both delayed in time and have a probabilistic occurrence. If knowledge (as well as imposition) of such consequences also is

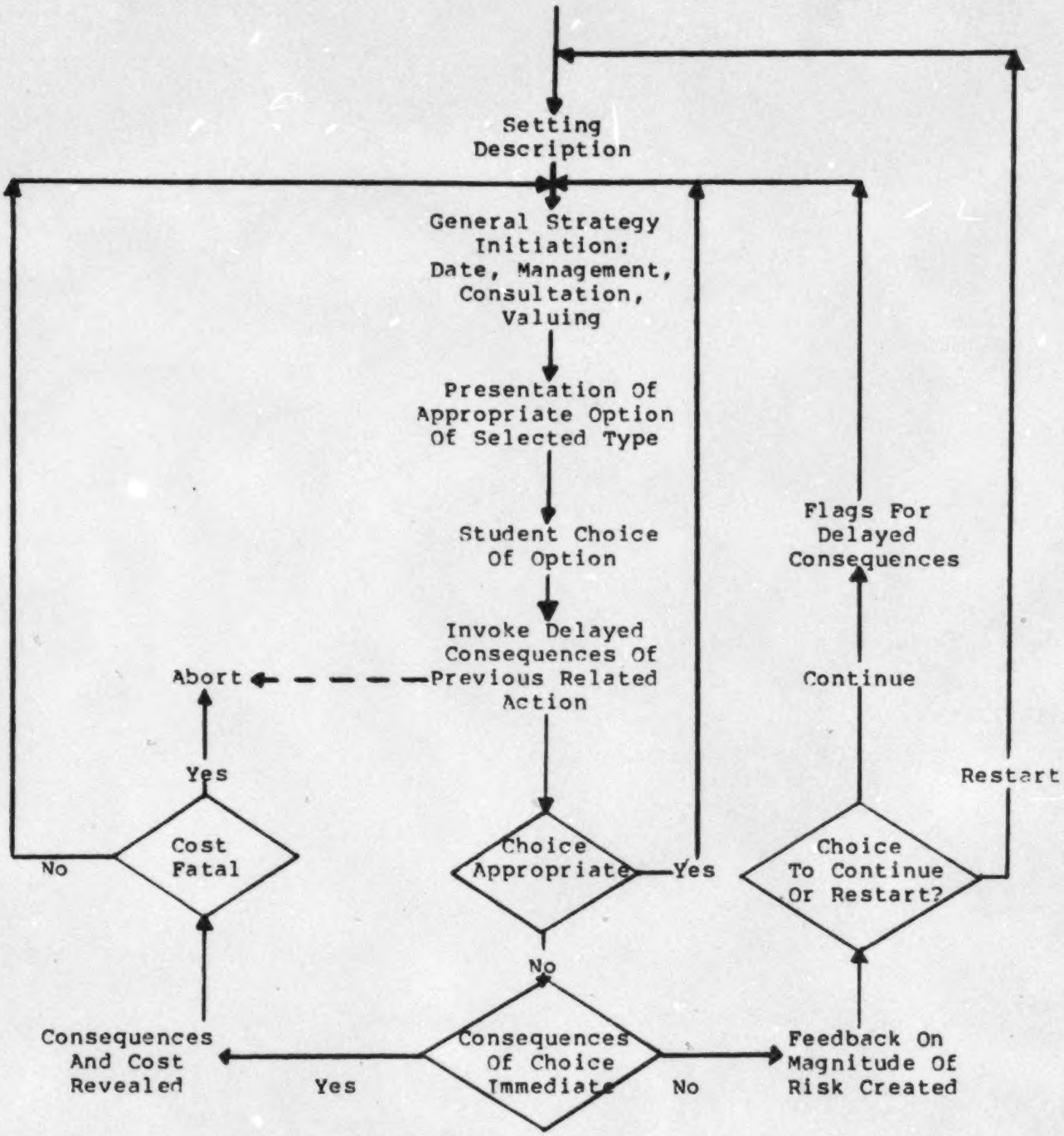


Figure 4

General Algorithm for Computer Simulation in Decision Making or Diagnostic Training

delayed, revelation of their prospect might be avoided by chance. This, of course, is what could happen in reality. However, we argue, this is a feature on which a training simulation should be at variance with its universe. A major reason for this is that in the simulation, one has the opportunity deliberately to pursue less than optimal paths through the decision maze. Early confirmation of an impending peril provides the student with an opportunity carefully to observe and to explore the varying dimensions of these less desirable aspects of the phenomenon.

The treatment of delayed and, perhaps, probabilistic consequences of option choices is reflected in the general algorithm (figure 4) through the sequenced decisions on the appropriateness of a student's choice and the immediacy of its consequences. In the double negative state of these decisions, the student receives feedback on an impending peril and on its likelihood and magnitude. The student then has the choice of continuing the simulation or of starting the simulation over to reinforce the correction of the misjudgement just made.

CONSTRUCTING A SIMULATION

This discussion is designed to assist any attempts a teacher might make in building new simulations for use in instruction. The following ideas also will serve as a foundation from which the teacher can make decisions about the quality of simulations obtained through publications, from colleagues, or from other sources of computer courseware.

The first, and most important, piece of advice to a teacher attempting the building of a simulation style computer lesson is to refrain from addressing the computer and from beginning the programming activities too soon. Much effort can be saved, as is the case with many of the other styles of instructional computing, by careful planning, research, and thinking before initial attempts at creating a computer program. Starting a computer simulation program too early, before carefully having considered its contents and before having made the variety of important decisions about its nature and intended uses, almost always results in the necessity to start the programming task anew at some intermediate point. Both computer time and a teacher's time are much too valuable to be utilized in such a haphazard fashion.

The first step in building a simulation, of course, is having the idea for the setting and the phenomenon to be simulated. As mentioned earlier, a simulation can exist for any phenomenon characterized by a problem to be solved, a goal to be reached, a procedure to be executed or learned, or an environment to be understood. Many things involved in a wide variety of school subjects and topics would yield an interesting and useful simulation. We stress that simulation is NOT an instructional computing style appropriate only for mathematics or science teachers.

Once the setting or phenomenon has been selected, the next step is to write the opening scene. This is important at this stage because, in so doing, the builder must face several of the decisions that have an important bearing on the design and contents of the finished product. In the opening scene, one must describe the setting of the simulation in a proper amount of detail. One must include all the attributes or features of the environment that readily are observable in reality. A balance is required between overwhelming the participant with descriptive data and being too obscure. Very explicit in the opening scene should be a specific statement of the participant's role in executing the simulation and a clear statement of the task or goal the participant is to reach. In making the decision on the participant's goal or task, the builder determines whether the resulting simulation will be of the replicable performance variety or of one of the other types.

Some artistry is involved in designing a good opening scene. Overwhelming the participant with irrelevant data tends to confuse and discourage the participant. At the other extreme, overly digesting the environment can cause the task or solution to be obvious to the participant. Some selected irrelevancies from the environment are appropriate to include in the detail. These serve to "paint the picture" more realistically and to incline the participant to identify more closely with the role being assumed.

Constructing the set of option pairs is the bulk of the work in building a simulation. An efficient way to proceed is to have a deck of file cards (say 3"x5" index cards) each of which represents a single option pair. On one side of a card one writes the first component of an option pair, a specific choice or decision available in the environment. On the other side of the card is recorded the consequences of that choice or decision. It usually is helpful to have codes for recording the type of choice (data gathering, management, consulting, valuing) and for recording the nature of the consequences (necessary, expediting, etc.) and the point in time of the consequences (immediate or delayed).

The option pairs most easily recorded first are those comprising one of the optimal solution paths. If several optimal solutions exist, record the option pairs of each of them at this time. Once this is completed, then the real work of simulation building begins. That is the identifying and recording of as many possible alternate decisions that could be made at each decision point of the situation. Care must be taken to include options of both the helpful and the hindering variety. Participants must be provided access to all those choices (good, bad, or neutral) that would be accessible in the real context. Options should be included that correspond to solution attempts based upon common misunderstandings or misconceptions concerning properties or aspects of the phenomenon. It is easy to see that this task will result in a large deck of cards rather quickly.

Sometimes the manufacture or identification of the available options other than those in the solution paths can involve extensive research and hypothesizing. Take, for example, an attempt to build a simulation of the Cuban Missile Crisis which took place during the John F Kennedy administration in the United States. Recall that, briefly, the situation involved Russia's attempt to install several offensive weapons on the island of Cuba and the efforts of the United States government to prevent same. In simulating this situation, we might give the participant the role of President of the United States with a goal of resolving the missile problem and, also, of avoiding a war. We might further define as one solution path the sequence of choices which President Kennedy actually made. All of this information is a matter of public record and is easily found. Now the real work

begins when we begin to ask "What other choices could President Kennedy have made?". Further we need to hypothesize as accurately as we can on the probable consequences of each of these choices. To gather this information we might need to scour old newspaper reports and editorials, search out memoirs and other writings of persons such as the Joint Chiefs of Staff and leading Congressmen at the time, etc. It is clear that this is no trivial task but, when completed, it will add many dimensions to a resulting simulation of the event.

Once all of the option pairs are detailed, one then will be able to sort the cards into major categories representing the general choices of the strategy initiation section.

At the very earliest, one begins to construct the computer program for the simulation after the opening scene has been described and the solution path(s) have been identified, since these are the contents of an "absolute minimum" logic network for the simulation. It usually is more efficient, however, to postpone computer programming until the entire deck of option pairs has been constructed. In this way, important details and conditions surrounding those pairs having delayed consequences will be known as the computer program is built.

The design and inclusion of the necessary transition messages is done as one of the last programming tasks and continues into the initial trials of the simulation with representatives of the student audience.

SUMMARY

This paper has presented a discussion of computer simulation as a tool for teaching about phenomenon characterized by a problem to be solved, a task or goal to be reached, a procedure to be learned, or an environment to be understood. To characterize and define simulation we have looked both at the attributes that are common to simulations and at a taxonomy (classification) of simulations based upon attributes not common to all instances of simulation. Finally, we have included a discussion of the many aspects of using simulations in the classroom.

Simulations can be a valuable, and very different, teaching tool. However, much time and energy can be wasted by their use if the teacher is not acutely aware of their nature, what they potentiallly can provide in the way of learning experiences, and the provisions that must be made to optimize their use.

SIMULATION LISTING

(Lists of existing simulations in a variety of subjects are available from the following sources. This list is not intended to be exhaustive.)

CONDUIT, P.O. Box 388, Iowa City, Iowa 52240.
Distributors of a wide variety of simulations for the sciences, social sciences, management.

Digital Equipment Corporation, Software Distribution Center, Maynard, Massachusetts, 91754.
Distributor for the Huntington II Project simulations in the sciences and social sciences.

(Following are sources of non-computer games and simulation. Many of these can be computerized with little effort.)

Belch, Jean (ed.), Contemporary Games, Gale Research Company, Vol. I, 1973; Vol. II, 1974, Detroit.
A directory of several hundred games and simulations for instruction in various subjects.

Horn, Robert, The Guide To Simulations/Games for Education and Training, Vol. I and Vol. II, Academic and Business, Didactic Systems, Inc., Cranford, New Jersey, 1977.
A very current and comprehensive listing of simulations and games for instruction.

Hounshell, Paul B. and Ira R. Trollinger, Games for the Science Classroom, An Annotated Bibliography, National Science Teachers Association, 1742 Connecticut Avenue, N.W., Washington, D.C., 1977.
A listing of games and simulations for use in teaching various science courses.

Stadsklev, Ron, Handbook of Simulation Gaming in Social Education (Part II), The University of Alabama: Institute of Higher Education, Research, and Service, 1975.
An annotated index of sources.

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